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SPACE OPERATIONS CENTER

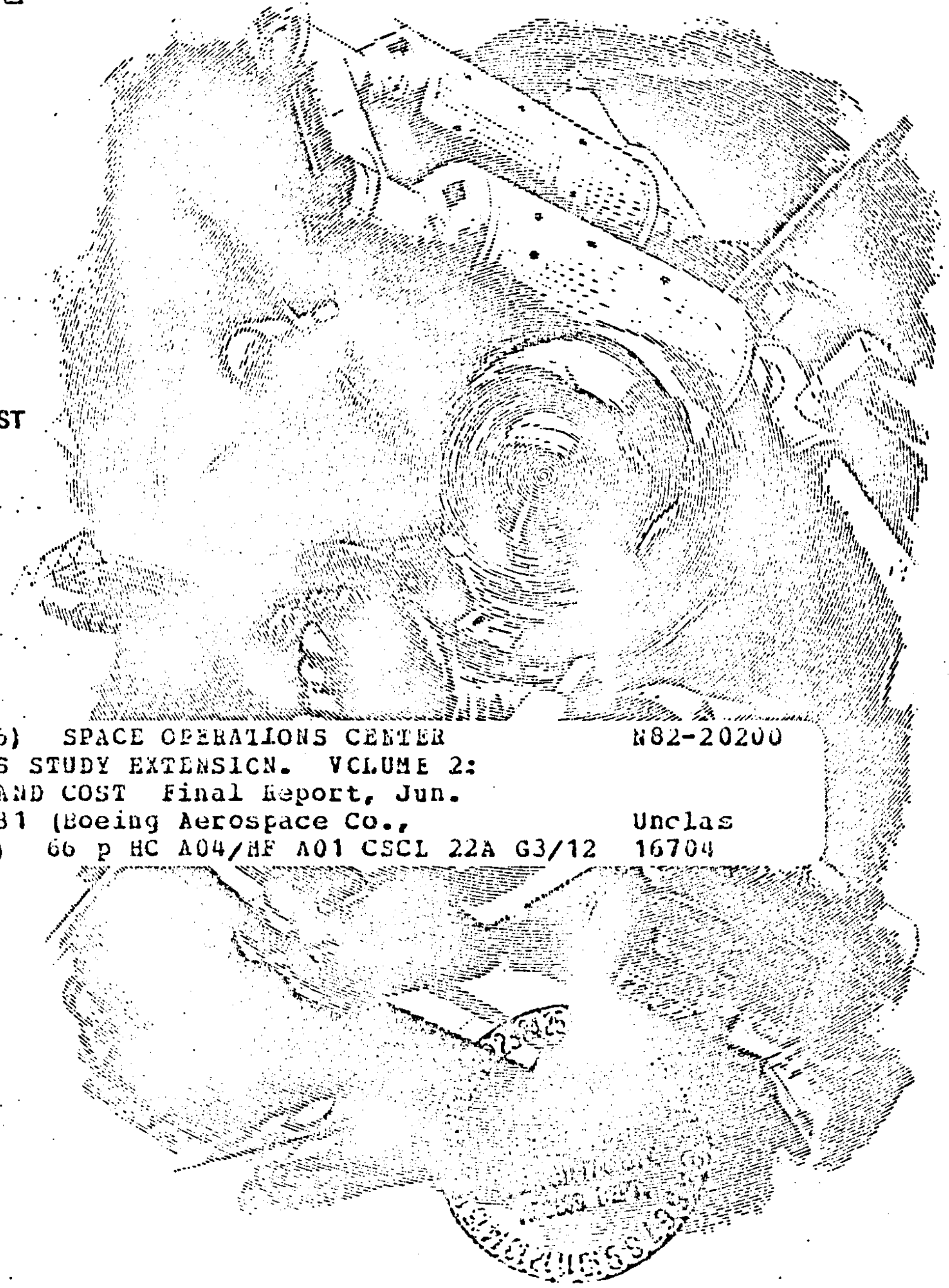
SYSTEM ANALYSIS

STUDY EXTENSION.

FINAL REPORT
VOLUME II

PROGRAMMATICS AND COST

D180-26785-2



(NASA-CR-167556) SPACE OPERATIONS CENTER SYSTEM ANALYSIS STUDY EXTENSION. VOLUME 2: PROGRAMMATICS AND COST Final Report, Jun. 1980 - Dec. 1981 (Boeing Aerospace Co., Seattle, Wash.) 66 p HC A04/MF A01 CSCL 22A G3/12

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D180-26785-2

SPACE OPERATIONS CENTER
SYSTEM ANALYSIS
STUDY EXTENSION

Conducted for the NASA Johnson Space Center
Under Contract NAS9-16151, Exhibit B

FINAL REPORT
VOLUME II

PROGRAMMATICS AND COST
D180-26785-2

January 1982

Gordon R. Woodcock

Approved by
Gordon R. Woodcock,
SOC Study Manager

BOEING AEROSPACE COMPANY
P.O. BOX 3999
Seattle, Washington 98124

FOREWORD

This executive summary report synopsizes the results of a contracted study of a manned Space Operations Center. The study was an outgrowth of an earlier study conducted at the NASA Johnson Space Center in 1979. The contracted activity began in June of 1980. The initial contract increment covered the period from June 1980 through July of 1981. A set of contract reports were provided to NASA at the conclusion of the initial contract increment. A subsequent contract increment was initiated in August of 1981 and technical work was completed in December 1981. This executive summary report covers the results of both the initial contract increment and the add-on increment. It therefore reflects the results of the entire study.

This study was managed by the Lyndon B. Johnson Space Center. The Contracting Officers Representative and Study Technical Manager was Sam Nassiff. This study was conducted by The Boeing Aerospace Company, Large Space Systems Group with Grumman Aerospace and the Hamilton Standard Division of United Technologies as subcontractors. The Boeing study manager was Gordon R. Woodcock. The Grumman study manager was Ron McCaffrey. The Hamilton Standard study manager was Harlan Brose.

This final report includes five documents:

D180-26785-1	Vol. I	-	Executive Summary
D180-26785-2	Vol. II	-	Programmatics
D180-26785-3	Vol. III	-	Final Briefing
D180-26785-4	Vol. IV	-	SOC System Analysis Report
D180-26495-2 Rev A		-	SOC System Requirements
D180-26495-3 Rev A		-	SOC System Definition Report

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LIST OF ACRONYMS AND ABBREVIATIONS

DDT&E	Design, Development, Test, and Evaluation
DM	Docking Module
ECLSS	Environmental Control/Life Support System
GTV	Ground Test Vehicle
HM	Habitat Module
IR&D	Internal Research and Development
IVA	Intravehicular Activity
JSC	Johnson Space Center
KSC	Kennedy Space Center
LM	Logistics Module
ME	Mission Equipment
OTV	Orbital Transfer Vehicle
PCM	Parametric Cost Model
RCS	Reaction Control System
SM	Service Module
SOC	Space Operations Center
WBS	Work Breakdown Structure
WTR	Western Test Range (Vandenburg AFB)

1.0 INTRODUCTION

The initial study of Space Operations Center programmatics (Boeing-19, Section III and Boeing-20, Section 18) included considerations of program structure, cost, hardware commonality, schedules, and program phasing. The follow-on study included tasks that required that the development plan be updated, that planning options be developed, and that a SOC user charge plan be created. This document presents the integrated discussions of program structure, cost, schedules, system buildup options, funding profiles, and recommended technology levels that resulted from both studies.

This report was prepared to provide a convenient summary of the results of the Space Operations Center (SOC) Phase A Study relating to SOC cost, program options and program recommendations.

Program options were analyzed with respect to mission needs, design and technology options, and anticipated funding constraints. A reference design for the Space Operations Center provided the basis for cost analyses, but the programmatics analysis found an alternate design to be preferable in view of estimated mission needs and funding requirements and constraints. The reference and alternate designs, and technical rationale for preference of the alternate are discussed below under Design and System Options.

2.0 SUMMARY OF MISSION NEEDS

A mission needs analysis was conducted to provide a basis for SOC requirements, designs, and program recommendations. This analysis is reported in detail in Volume 3 of this document set. A brief summary and conclusions are presented here.

Mission models were derived from historical trends, NASA planning documents, and from budgetary and economic considerations. Budgetary and economic factors were given dominant consideration over all other factors. Mission forecasts from earlier mission models were adjusted (in most cases downward) to conform to estimated budget realities. Economics-based forecasts were used for commercial uses of space.

The result was a set of mission models that were dominated by the commercial and defense sectors. This outcome was not surprising inasmuch as economic growth and adequate defense are important national priorities; the approach used for development of the models inherently reflects such priorities.

Three models were created, representing low, median, and high projections of future space activities. A summary of the models is presented in Figure 1. These graphs show mission events (not shuttle flights!) per year, divided into the major mission model sectors.

The mission models were analyzed to determine their demand for space transportation and SOC services. Alternative ways of satisfying the transportation demand were investigated. It was found that the most effective space transportation option was use of the space shuttle with a high-energy aerobraked, space-based orbit transfer vehicle. The transportation demand can be satisfied with 40% fewer shuttle flights by the advanced-technology OTV as compared with an all-propulsive ground-based OTV. Aerobraking offers the greatest leverage; space-basing and implementation of shuttle external tank scavenging to improve propellant logistics operations were also found to offer cost benefits.

With the advanced-technology upper stage, the low and median mission models could be satisfied by a five-orbiter fleet, assuming each orbiter can be used ten to

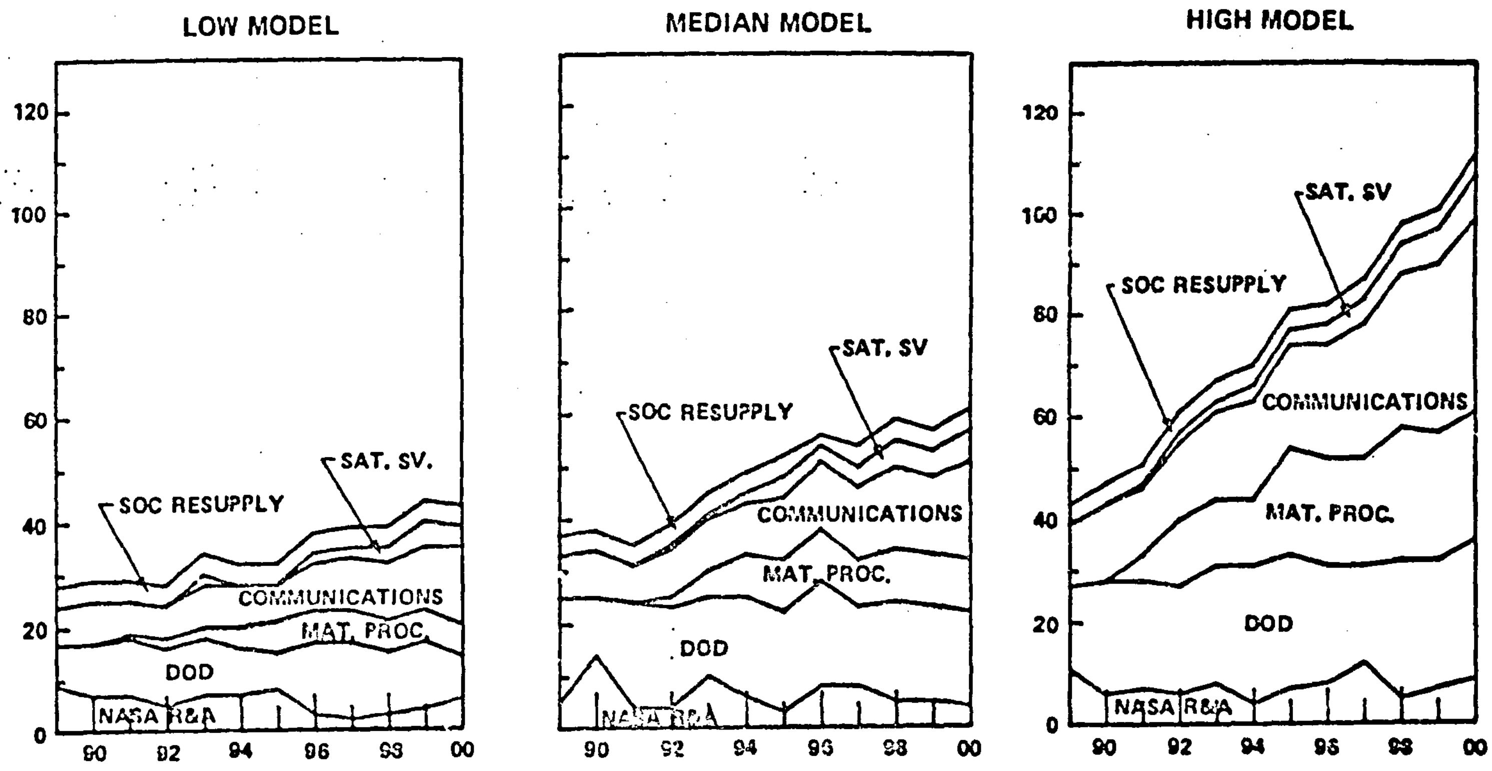

Figure 1. Comparison of the Mission Models

twelve times a year. The high model demand exceeds one hundred shuttle flights by the year 2000. This model represents a forecast in which extensive commercial and military operations are carried out in space. Development of a second-generation space transportation system by the mid 1990s is consistent with the high model scenario.

Demand for SOC services in the low and median models could be satisfied by the SOC designs described in the following section of this report. In the low model, a single station with a crew of 12 suffices. In the median model, implementation of a second SOC by about 1995 is needed; the second station would be dedicated to research and applications operations, primarily life sciences and materials processing development. The high model requires a total of more than fifty people in space by the year 2000. As is true for space transportation, development of a second-generation or much expanded space station would likely occur by the end of the century in this scenario.

3.0 DESIGN AND SYSTEM OPTIONS

The reference SOC design illustrated in Figure 2 meets the system requirements contained in the SOC requirements document. However, a number of reasons have developed for considering alternative modular concepts. The principal ones are the following:

1. A number of alternative uses for the basic hardware set and technology have been identified, including military applications, small geosynchronous stations, and stations designed primarily to support materials processing development and other science and applications operations.

2. If it were desired to place a manned station into a high inclination orbit, it would be necessary to have modular flexibility. The weight of each module would have to be compatible with the Shuttle payload capability limitations for high inclination launches from WTR.

3. Simultaneous development of a Service Module, a Habitat Module, and a Logistics Module, as postulated for the reference program, leads to funding profile problems. The required funding escalates more rapidly and peaks at higher levels than anticipated funding capabilities. In order to resolve this issue, a system design is needed that leads to initial operations with fewer simultaneous developments.

4. The mission needs analysis conducted as a part of this study identified a need for a Space Operations Center accommodating up to 12 people for the median traffic model by the year 2000. (A second station, devoted entirely to microgravity applications, with a crew of eight, may also be needed by the year 2000.)

5. The same mission needs analysis indicated that an initial operational capability with a crew of four would suffice for a period of two to four years. This assumes that the orbit transfer vehicle would be ground-based for this period of time. An incremental build-up approach is most compatible with these mission needs.

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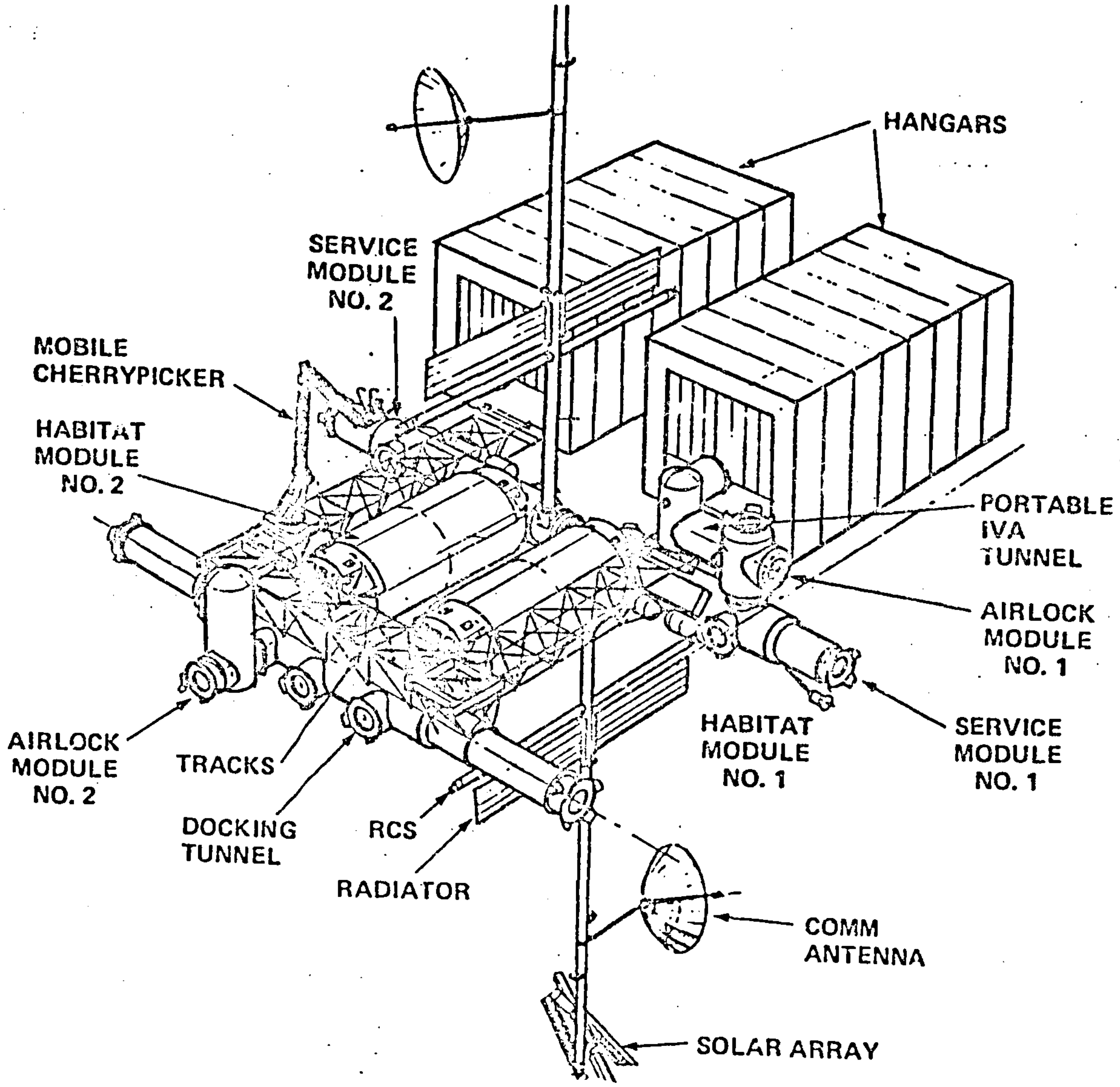

Figure 2 Operational SOC Configuration

6. The mission needs analysis indicated a need for additional interior space for science and applications missions.

3.1 ALTERNATIVE MODULE AND SUBSYSTEM DESIGN PHILOSOPHY

The need to create a manned space station technology adaptable to diverse missions has led to a versatile modular approach to space station design. The keys to this approach are (1) standard subsystems employing advanced technology to permit a long, useful life without obsolescence, and (2) modularization of the design at a level below that of complete station modules to allow creation of a variety of system configurations. Preliminary results indicate versatility to render a design as small as a single Shuttle-launched station and one large enough to support a crew of 12 to 20, all employing the same basic hardware set.

This alternative approach evolved from the original SOC Service Module. The Service Module includes the essential elements of a space station, including electrical power supply, consumables supply, and elements of the environmental control, thermal control, data management, and communications subsystems.

The first step in this evolution was equipping of the reference Service Module with emergency survival equipment, so that in an emergency, one Service Module could provide subsistence and life support for up to four crew members.

The next logical step improved the habitability provisions in the Service Module so that it alone could serve as a modest space station with adequate, if austere, habitability provisions. The improvement of accommodations led to increasing part of the service module diameter to improve its habitability, a concept initially explored in an IR&D investigation of a small single-launch military space station.

Two alternative Service Module options evolved. One was called the "German Hand Grenade" concept, with a short section 4.4 meters in diameter, attached to a tunnel section approximately two meters in diameter. The stores and equipment that had been located on the 2.5-meter diameter section of the original service module were packaged on the 2-meter diameter section of the German Hand Grenade module as illustrated in Figure 3.

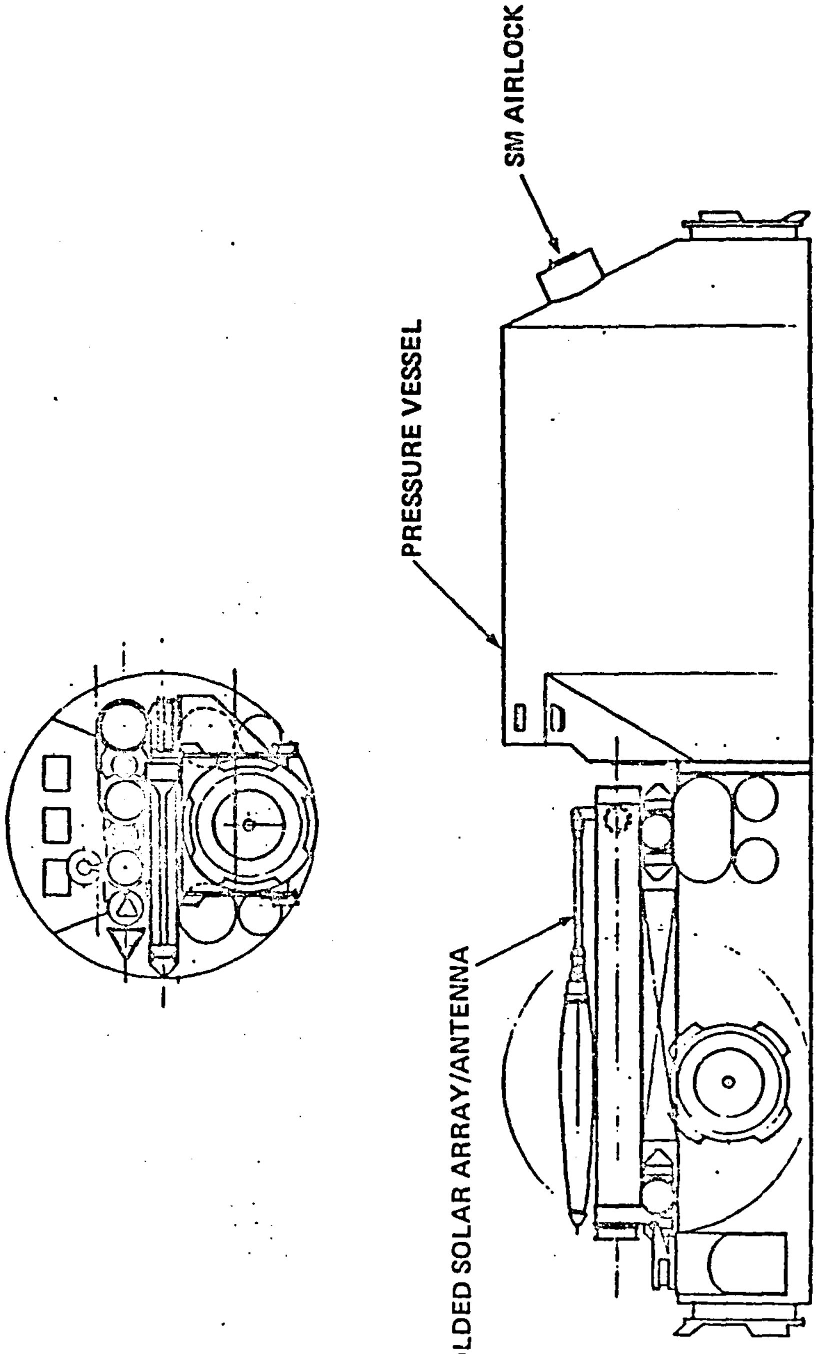

Figure 3. German Hand Grenade Concept

Further development of this approach has evolved a smaller diameter, but longer, habitability section for the modified Service Module. Reducing the diameter allows masts and booms to be packaged alongside the larger diameter section. This minimizes the number of joints. Packaging volume along the small-diameter sections at the ends is adequate for tanks and other external stores. The subsystems alternatives are discussed later in this section. Table 1 gives a mass estimate for this Service Module.

The relative lengths of the large and small diameter sections of this modified Service Module are dictated by the volume requirements for external stores. A representative configuration is sketched in Figure 4.

A deficiency of the German Hand Grenade concept was a shortage of berthing ports to accommodate space transportation equipment in the space-based upper stage scenario. A space-based upper stage used for the median traffic model requires two berthing ports for propellant tanks, and two additional ports for OTV hangars. At least one further port is required for the manned cabin section of the manned orbit transfer vehicle. This port need not necessarily be on the bottom side of the configuration.

Additional ports are also needed for resupply modules, experiment modules, and space testing pallets. It is important that these accommodations not encroach into the satellite servicing and space construction section of the station. The Service Module must provide an adequate number of ports. Installing ports in the full-diameter section of the German Hand Grenade concept requires recessing of the port with attendant structural complexity and encroachment into interior volume areas.

Habitat Modules of 4.2 meters diameter can be added to the program at a later date. The versatile modular design approach permits the length and interior arrangements of these habitats to be tailored to the mission requirements. For a SOC in low inclination, low Earth orbit, a full-length (14-meter) habitat system can be incorporated. Two such habitats will accommodate up to eight additional crew, for a total of 12. Overflow capacity within these modules is also available in the form of additional area that can be devoted to sleep stations for transient visitors not allocated a private quarters area.

Table 2

SOC-1589

Habitable Service Module
Mass Summary

Title	Nickel Hydrogen Battery Energy Storage Mass kg (lb)	Regenerative Fuel Cell Energy Storage Mass kg (lb)
Structures	6798 (14987)	6798 (14987)
Mechanisms	408 (899)	408 (899)
Thermal Control	1454 (3206)	1364 (3007)
Aux Propulsion	483 (1065)	587 (1294)
Ordnance	10 (22)	10 (22)
Electrical Power	3983 (8781)	3478 (7667)
G N & C	420 (926)	420 (926)
Tracking & Communication	653 (1440)	653 (1440)
Data Management	481 (1060)	481 (1060)
Instrumentation	100 (220)	100 (220)
Crew Accommodation	306 (675)	306 (675)
EC/LSS & Crew Systems	1911 (4213)	1911 (4213)
Mission Equipment & Consumables	2594 (5719)	1844 (4065)
Growth	4082 (8999)	3854 (8497)
Total	23683 (52212)	22214 (48973)

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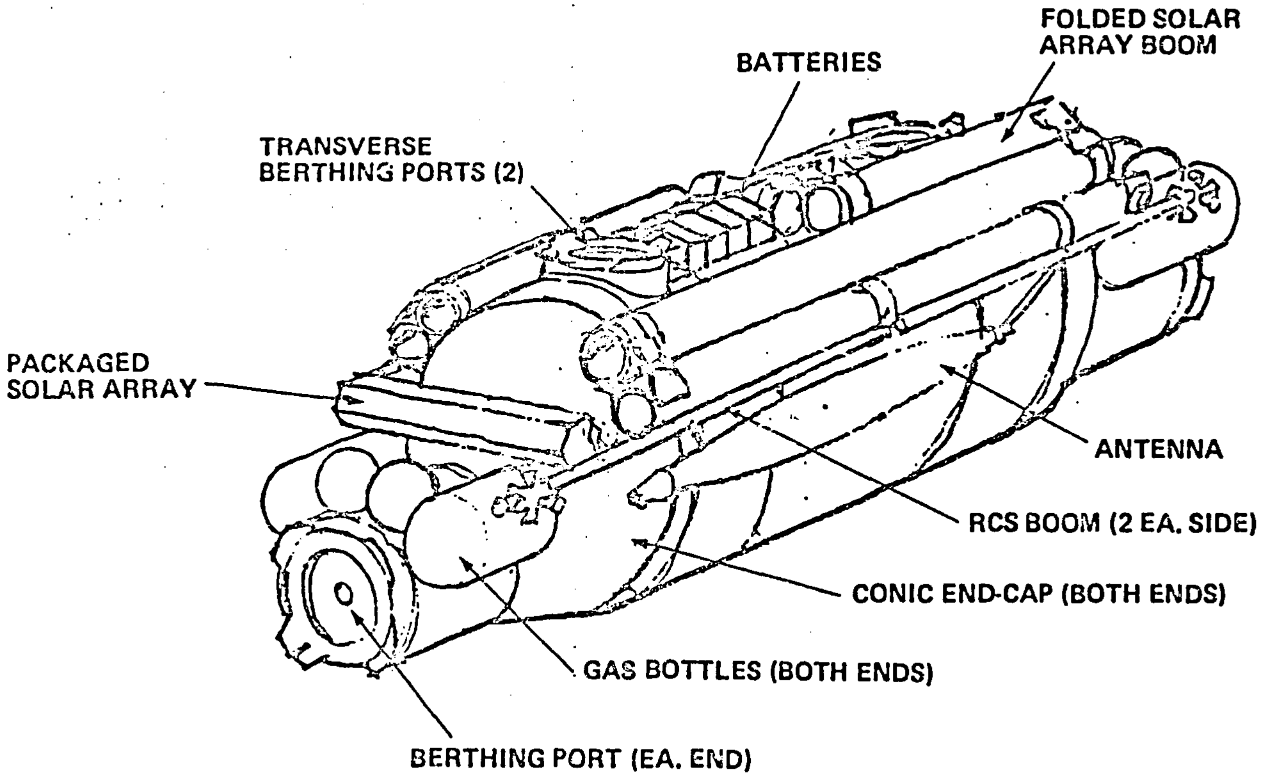

Figure 4 Service Module Configuration

Electrical power modularity and adaptability is provided by design of a standard power section incorporating solar arrays and energy storage. These elements are modular at a level that permits a smallest increment of raw power supply on the order of 10 kilowatts. Units can be grouped together to provide higher power levels. The array size is tailored to the power level desired. System redundancy improves as power level is increased. Each module of any station element will receive raw power from the power supply and will provide its own power conditioning.

Data management modularity is provided through federated processing. This is a variant of distributed processing in which each processing element is capable of operating stand-alone, but is tied to a data bus for sharing of data with other processors to enhance integrated operation of the entire system. Advanced processors will ensure that adequate capability exists to accommodate any conceivable requirement. Rapid advances in microprocessor technology now offer computing power overkill as cheap insurance against future limitations. A standardized high level language, probably ADA, will be employed.

The environmental control and life support system will incorporate air and water processing equipment in two-man increments. Equipment is replicated to serve larger crews. A set of equipment designed to serve four or more people will degrade gracefully with failures. As the number of people served increases, the redundancy and resilience of the system also increases. Standardization of equipment and interfaces will enable all presently known needs to be served by the basic equipment set.

At the two-man level, i.e., in a single-launch space station, the environmental control and life support system will have only fully operational and fail-safe modes. A major failure would require initiation of emergency mode operations. Attempts to restore the system to service would be carried out in parallel with initiation of rescue plans. For any station larger than the basic two-man increment, fail-operational, fail-safe capability would exist.

A standard set of communications equipment will serve a variety of needs. Communication needs in UHF, S-band, K-band and micro-wave have been identified for the SOC missions. These will serve most applications. Special

equipment and features may be required for cer· in military applications. These can be interconnected with the standard equipment set through standardized interfaces. Use of fiber optics communication buses throughout will facilitate meeting communications security requirements for any special applications.

The recommended alternative SOC implementation sequence related to the median traffic model and mission needs analysis proceeds as follows:

A single Service Module is launched by the initial Space Shuttle flight. This module will include the basic SOC command and control work station, together with food preparation, hygiene, suit storage and contingency sleep sections. This initial Service Module could be used as a two-man space station. It would provide relatively comfortable accommodations for a crew of four when docked with a Shuttle Orbiter.

A second Shuttle launch would bring up a second Service Module identical to the first except for different interior arrangements. This second module would contribute sufficient habitability features to allow the two modules to accommodate a crew of four in reasonable comfort.

This initial station comprised of two Service Modules would satisfy the median model identified mission needs for SOC for two to three years. These mission needs include shakedown of SOC operations, early research and applications missions, demonstration of the essential technologies required for space-basing the Orbit Transfer Vehicle, and flight support operations for a ground-based Orbit Transfer Vehicle.

Three or more years after the initial SOC launches, a sequence of three additional build-up launches would complete the basic station configuration by adding two habitat modules and a docking tunnel leading to the configuration illustrated in Figure 5. This configuration could accommodate up to 12 people and accommodate all of the mission needs identified for SOC through 1995 to 1996. At the time transition to space-based OTV operations is desired, four additional Shuttle launches would bring up two space-based OTVs, two hangars, and two propellant storage tanks for the space-based OTVs. At this point, the SOC would be capable

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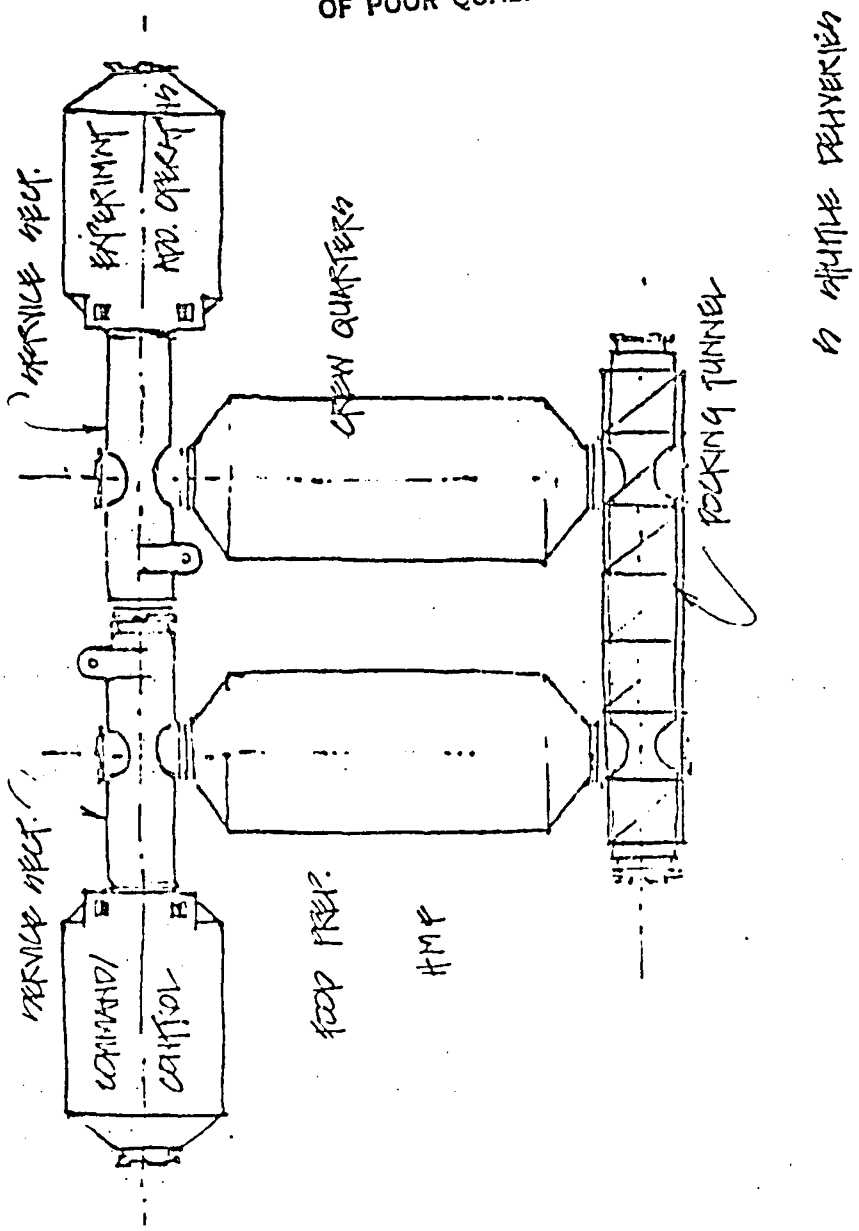


Figure 5 12-Man SOC Concept

of accomplishing all of the mission functions identified in the mission needs analysis.

In the latter part of the 1990s, an increase in the anticipated mission needs for science and applications, especially materials processing, coupled with a gradual decline in available power for support of experiments because of degradation of the solar array, would motivate the build-up of a second SOC dedicated to the science and applications missions. This SOC would be designed to support a crew of eight with additional internal space made available for science and applications operations, as well as the use of berthing ports to support research and applications pallets and modules in place of orbit transfer vehicles and construction projects. Shorter versions of the Habitat Modules might be used for this SOC configuration.

4.0 PROGRAM STRUCTURE AND WORK BREAKDOWN STRUCTURE

Recognizing the potential of setting precedents in establishing a work breakdown structure, we set forth the criteria in Table 2 as a precursor to preparing the WBS itself. These criteria are aimed at minimizing the program problems that could be introduced by an illogical WBS.

The SOC WBS that was used in the present study is shown in Figure 6. This WBS formed the outline for the System Description document and was the basis for mass and cost analyses.

1) THE WBS SHOULD BE INDEPENDENT OF PROGRAM PHASE. EACH ELEMENT INCLUDES ACTIVITY AND COST BY PHASE.

2) RESPONSIBILITY FOR EACH ELEMENT SHOULD BE CLEARLY ASSIGNABLE.

3. THE WBS SHOULD PRESENT LOGICAL WORK PACKAGES AND INTERFACES.

4) THE WBS SHOULD FACILITATE DIRECT MANAGEMENT CONTROL.

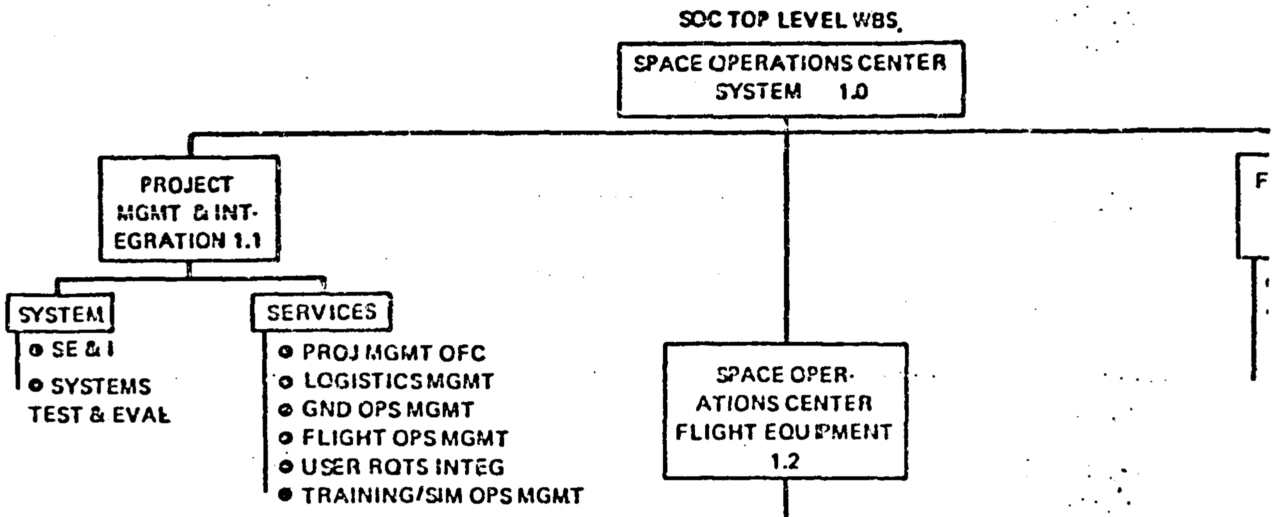
5) THE WBS SHOULD NOT INHIBIT FREEDOM OF CONTRACTING OPTIONS.

6) THE WBS SHOULD ENABLE STRAIGHTFORWARD COST MODELING.

7) THE WBS SHOULD ALLOW DIRECT DERIVATION OF SOC USER CHARGES.

8) THE WBS SHOULD BE A SUITABLE OUTLINE FOR REQUIREMENTS SPECIFICATION, SYSTEM DESCRIPTIONS, AND MASS AND COST ESTIMATES.

Table 2. SOC Work Breakdown Structure Criteria



		HABITAT MODULE 1.2.1		SERVICE MODULE 1.2.2			GENERAL PURPOSE SUPPORT EQUIPMENT 1.2.3			CONSTRUCTION SUPPORT EQUIPMENT 1.2.4			TRANSPOR SUPP EQUIPM 1.2	
	GENERIC SUBSYS. HARDWARE & SOFTWARE	HM-1, 1.2.1.1	HM-2 1.2.1.2	SM-1, 1.2.2.1	SM-2, 1.2.2.2	DT 1.2.2.3	MOB/ ACCESS 1.2.3.1	CP	MRWS	TT&F			HANGAR 1.2.5.1	DOLLY 1.2.5.2
1.2.X.X.1	STRUCTURES	x	x	x	x	x	x	x	x	x			x	x
2	MECHANISMS	x	x	x	x	x	x	x	x	x			x	x
3	THERMAL CONTROL	x	x	x	x		x	x	x	x			x	x
4	PRIMARY PROPULSION													
5	AC PROPULSION			x	x									
6	ORDNANCE	x	x	x	x	x	x	x	x					
7	ELEC POWER	x	x	x	x	x	x	x	x	x			x	x
8	GN&C	x	x	x	x									
9	TRACKING & COMMUNIC.	x	x	x	x				x					x
10	DATA MGMT & FLTS/W	x	x	x	x	x	x	x	x	x			x	x
11	INSTRUMENTATION	x	x	x	x	x	x	x	x	x			x	x
12	CREW ACCOMM.	x	x	x	x	x			x					
13	EC/LSS	x	x	x	x				x					
14	ASE, GSE, & STE	x	x	x	x	x	x	x	x	x			x	x
15	ASSY & C/O	x	x	x	x	x	x	x	x	x			x	x
16	SYSTEMS E&I	x	x	x	x	x	x	x	x	x			x	x
17	MISSION EQUIPMENT	x	x	x	x			x	x					

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Figure 6 SOC Work Breakdown Structure (WBS)

TER

FACILITIES 1.3

- LAUNCH SITE
- TRAINING & SIM
- OPS CONTROL CENTER
- SYS INTEG FACILITY

ONSTRUCTION SUPPORT EQUIPMENT 1.2.4			TRANSPORTATION SUPPORT EQUIPMENT 1.2.5				RESUPPLY & LOGISTICS SUPPORT SYSTEMS 1.2.6		
T&F			HANGAR 1.2.5.1	DOLLY 1.2.5.2	PROP SYS 1.2.5.3	SPARES 1.2.5.4	LM 1.2.6.1	TKR 1.2.6.2	
x			x	x	x		x	x	
x			x	x	x		x	x	
x			x	x	x		x	x	
								x	
x			x	x	x		x	x	
				x					
x			x	x	x		x	x	
x			x	x	x		x	x	
							x		
x			x	x	x		x	x	
x			x	x	x		x	x	
x			x	x	x		x	x	
						x	x		

SERVICES 1.2.7

- SE & I
- LOGISTICS
- OPS SUPPORT
- CREW
- EQUIPMENT
  - SUITS
  - EVA GEAR
  - PERS. EFFECTS
  - UTENSILS & TOOLS
  - ETC.

eakdown Structure (WBS)

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5.0 COST ANALYSES FOR THE REFERENCE SOC

Figure 7 illustrates the flow of the parametric cost estimating process. Two separate parametric cost models were used. The Boeing Parametric Cost Model, or PCM, is used to estimate hardware costs. It is based on historical experience from Boeing programs, and the structure of the model simulates cost experience for the functional elements of the Boeing organization. Rather than simply estimating dollars versus weight, the Boeing PCM estimates man hours versus weight (or other physical parameters), for design and for direct factory labor, and then applies historical experience factors for the various supporting functions of development shop, quality control, systems engineering, test, liaison, etc.

For large complex software systems, a parametric estimating method that factors software from hardware characteristics is not satisfactory. Consequently, the software cost estimates from Boeing PCM were suppressed to low values. These software estimates are considered representative of the software to be used as a part of the design, development and test process. The flight software was separately estimated utilizing the PRICE-S model developed by RCA.

Table 3 summarizes the results of the parametric cost estimating activity in terms of costs for the major program elements as a function of program phase. The costs tabulated for the operational and growth phases are additive to those estimated for the initial phases.

It is important to note that if the program is stretched out to create an extended gap between the initial and operational SOC, additional design and development expense will be incurred. Further, if the program is stretched to the point that the production operations for the program elements must be shut down and restarted, further additional manufacturing costs would be incurred.

The costs for the three phases of the reference SOC program are compared in Figure 8. These figures are not additive, i.e., each pie chart represents the total estimated cost through that phase of the program. The costs presented are totals for contract end items, and engineering and operational support items additive to the contract end items.

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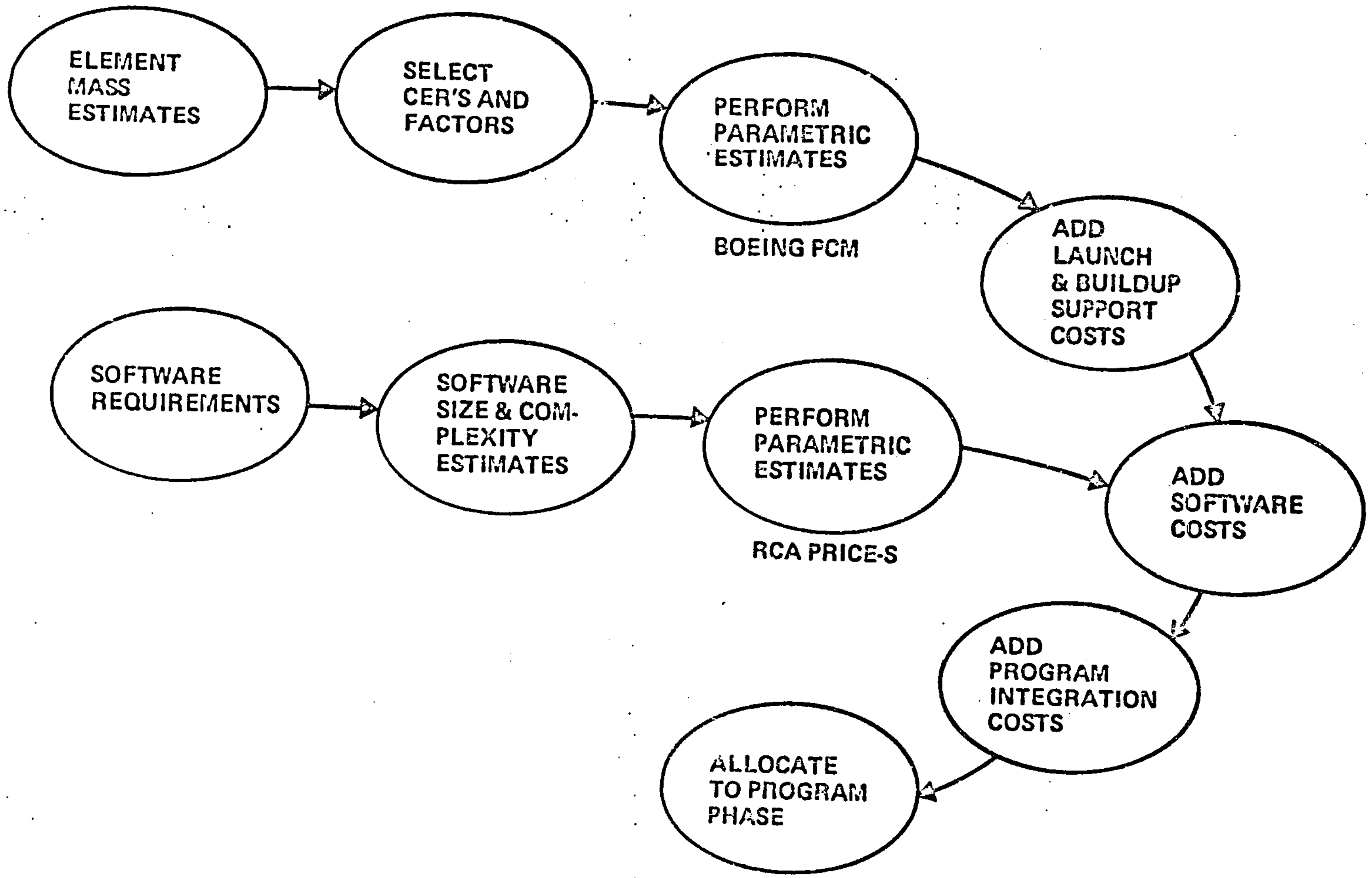


Figure 7 Cost Estimating Methodology

	INITIAL		OPERATIONAL		GROWTH	
	DDT&E	PROD	DDT&E	PROD	DDT&E	PROD
HABITAT MODULE	550	350	*	100	—	—
SERVICE MODULE	570	370	*	100	—	—
DOCKING TUNNEL	-0-	-0-	70	80	-0-	-0-
AIRLOCK (ROM)	30	30	-0-	20	-0-	-0-
LOGISTICS MODULE	80	90				
G-P SUPPORT EQUIP	25	15	250	150	50	50
CONSTRUCTION EQUIP	-0-	-0-	25	15	250	150
HANGAR (2)	-0-	-0-	70	50	-0-	-0-
OTV SPACE-BASING EQUIP (ROM)	-0-	-0-	-0-	-0-	175	130
SYSTEM SOFTWARE	230		100		70	
SHUTTLE FLIGHTS	-0-	120 (3)	-0-	160 (4)	-0-	120 (3)
BUILDUP SUPPORT	215	80	160	75	100	60
PROGRAM INTEG.	200	125	80	90	70	60
SUBTOTALS	1900	1180	755	840	715	570
TOTAL	3080		1595 ADDITIONAL		1285 ADDITIONAL	

* IF THERE IS AN EXTENDED GAP BETWEEN INITIAL & OPERATIONAL SOC, ADDITIONAL DDT&E REQUIRED

Table 3. Elements of Cost—Reference Program (1980 Dollars in Millions)

- MILLIONS OF 1980 DOLLARS (1982 DOLLARS % MORE)
- NO MISSION OR OPERATIONS COSTS
- NO COST IMPACT FOR PROGRAM STRETCH-OUTS

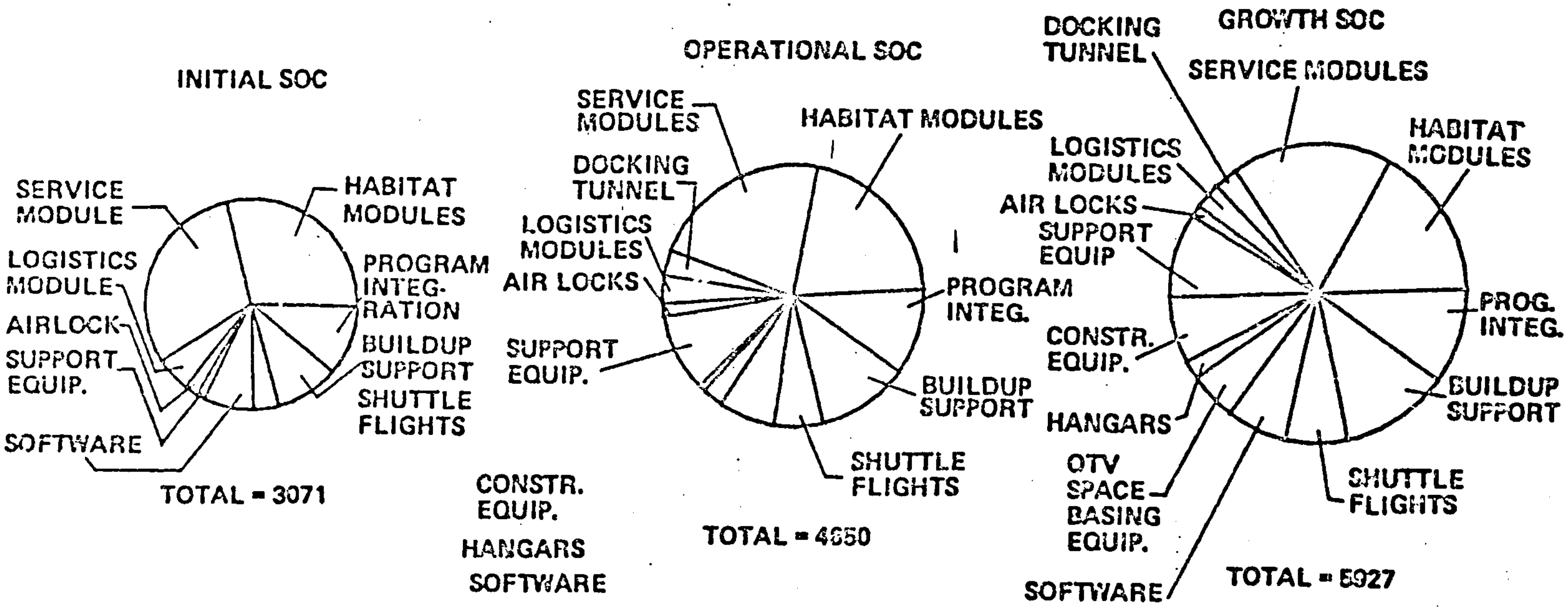


Figure 8 . SOC Evolution—Cost Composition by Element

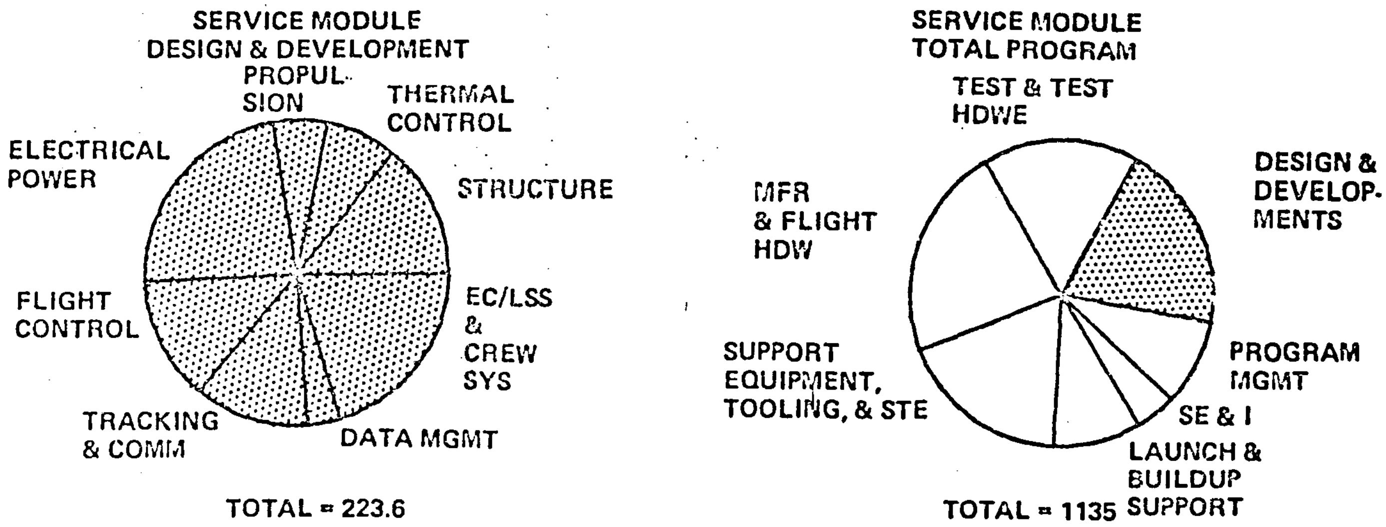
It may be seen that the habitat and service modules dominate the initial SOC program and become progressively less important as more program elements and mission equipment items are added.

The data displayed in Figure 9 show total costs for one contract end item. On the left-hand side are shown the costs associated with subsystem and system design and development. These costs are those required to process the subsystems through qualification. It may be noted that electrical power is the major subsystem in the service module. The ECLSS and crew systems include the emergency survival equipment added to the service module for the initial Space Operations Center configuration.

The right-hand pie chart shows total contract-end-item costs. As may be seen, design and development are only about 20% of the entire program. Other elements include test and test hardware, manufacturing and flight hardware support equipment, tooling, special test equipment, launch and build-up support, system engineering and integration, and program management. Commonality with concurrent or prior programs only leverages the cost of design and development of the flight hardware. This can provide significant cost savings, but forced commonality, using existing hardware ill-suited to the desired function can impact the other 80% of the total program cost. Forced commonality may incur a net cost increase rather than savings.

A preliminary estimate of the annual funding for the program is presented in Figure 10. The illustrated funding spread was developed for the operational SOC configuration using the data in Table 3, with the initial and operational SOC costs are combined. This is a relatively typical development program.

SOC-1031



- ELECTRICAL POWER IS THE MAJOR SUBSYSTEM
- EC/LSS & CREW SYSTEMS INCLUDES EMERGENCY SURVIVAL EQUIPMENT
- FLIGHT CONTROL INCLUDES COMPUTERS & CMG'S

- SMALLER PROPORTION OF LAUNCH & BUILDUP SUPPORT (COMPARED TO HM) ASSUMES HM ACTIVITY INCLUDES SYSTEM INTEGRATION ROLE

Figure 9. Service Module Cost Distribution through Operational SOC

SOC-1100

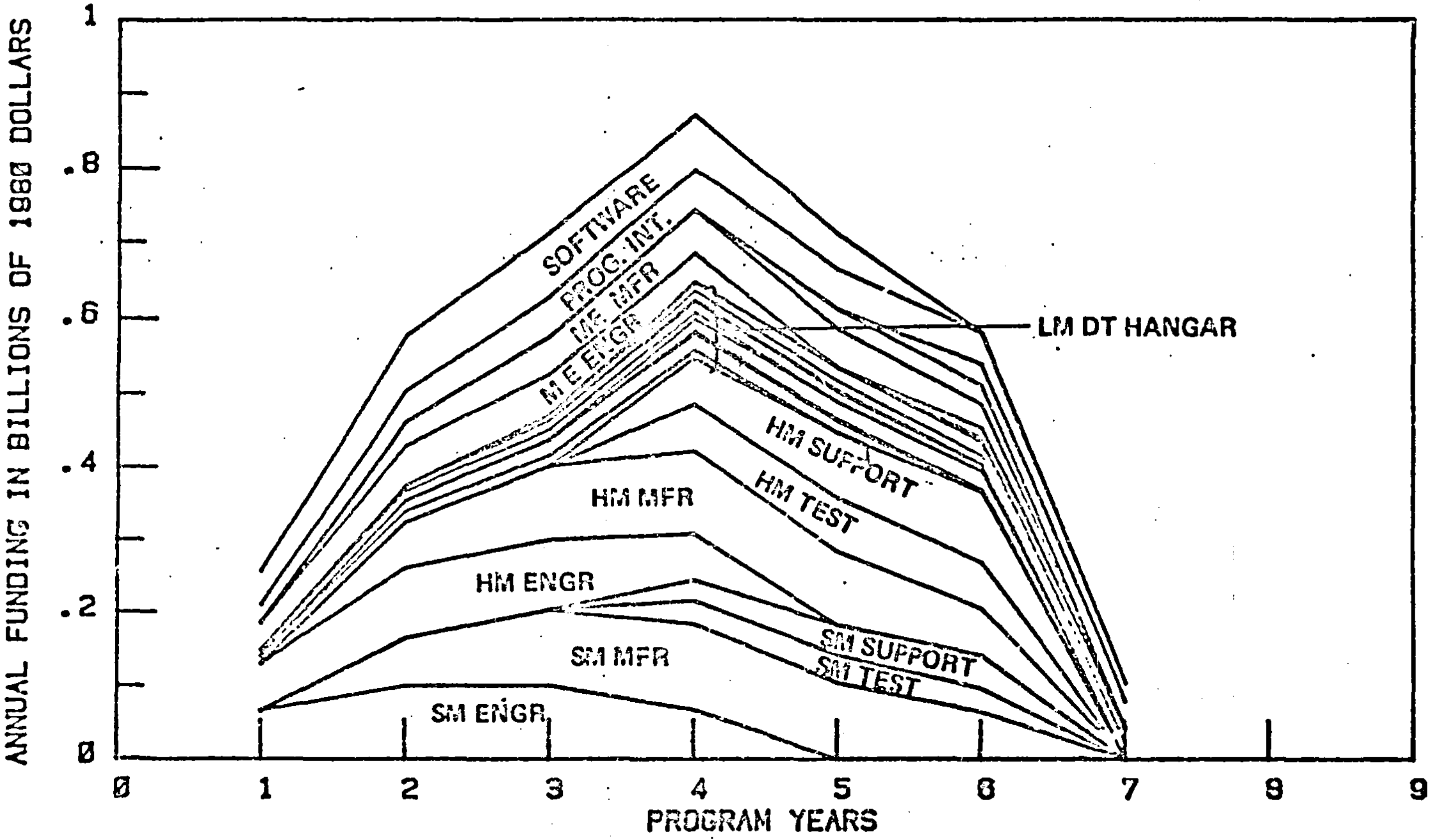


Figure 10. SOC Reference Program Funding

6.0 SCHEDULES AND SCHEDULE ANALYSES

Schedules for SOC development were laid out using analogous experience with programs of similar size and complexity. Certain assumptions are implicit in the schedules:

(1) Significant technology advancements will be carried at least to the proof-of-concept stage by technology advancement activities prior to initiation of Phase C/D for SOC. If the technology advancement is critical, a full technology demonstration may be required.

(2) Accordingly, program delays caused by technology immaturity will not be encountered.

(3) Shuttle launch service will be available on a timely basis for SOC buildup; further, the SOC buildup will not be constrained by availability of facilities at KSC.

(4) End item fabrication and test activities are phased so that one set of tooling for each end item type, and one test crew, can accomplish the required fabrication and testing.

The schedule analyses concentrated on the fabrication, test, and integration schedules incorporating assumptions (3) and (4).

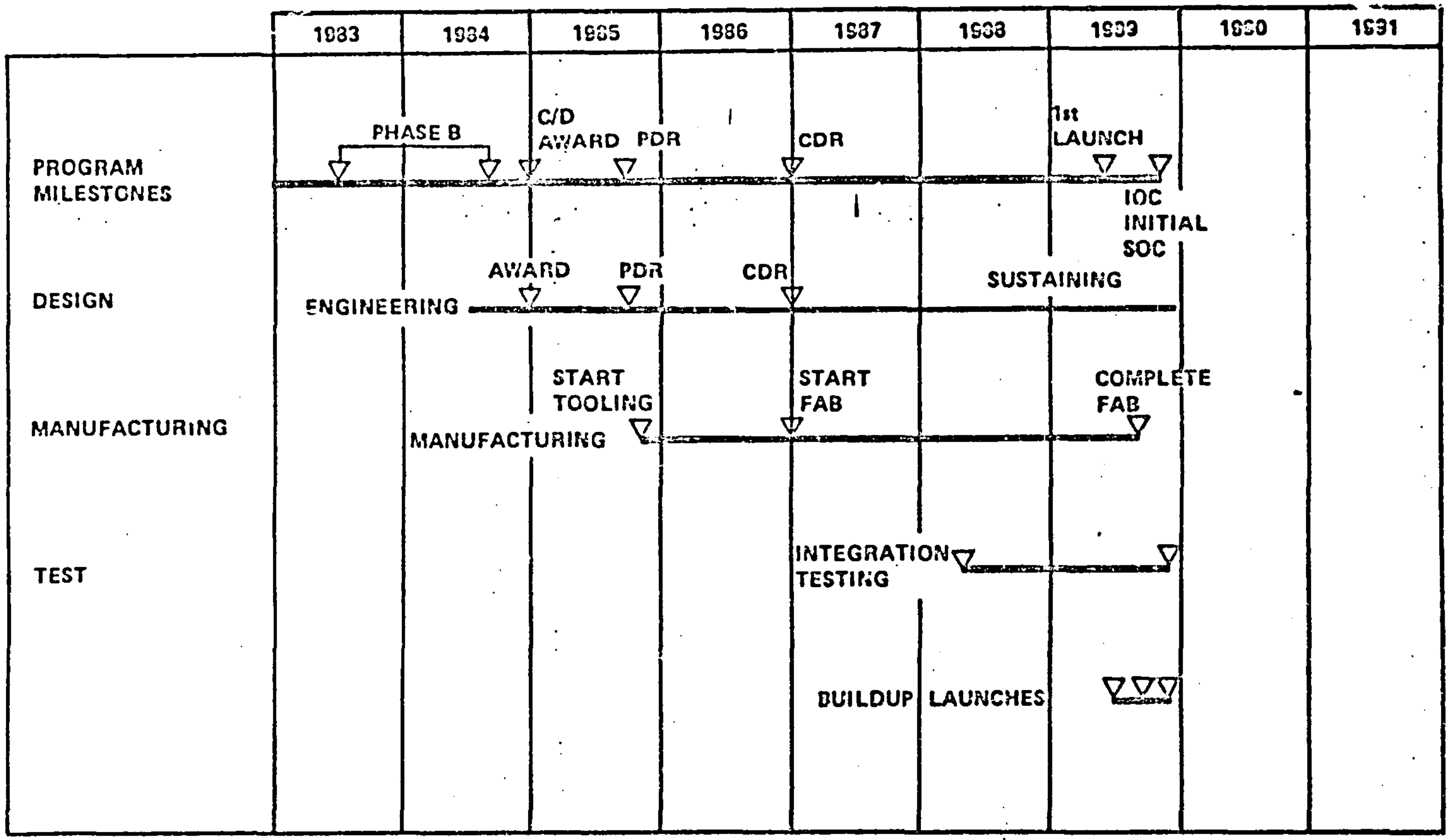
Because the flight SOC will be finally assembled in space by berthing modules together using the Shuttle, it was seen as very important to validate, both mechanically and functionally, the berthing interfaces on the ground before launch. Subsystems such as electrical power, EC/LS, communications, and data management interface through these berthing ports. This need led to the concept of a ground test vehicle (GTV). The GTV is comprised of one Service Module, one Habitat Module, one Logistics Module, and a Docking Tunnel interface simulator. All subsystems in the GTV will be flight or flight prototype hardware.

The GTV will initially serve an integration role to prove out the proper operation of the subsystems that interface through the berthing ports, and will later serve

to validate flight hardware interfaces at KSC before each flight article is launched. Finally, after the flight system is fully built up in orbit, the GTV will be returned to JSC to serve as a "hangar queen" for simulation, training, and checkout of procedures, subsystem updates, and software changes before these are implemented in the flight system. It will be necessary to begin training and simulation activities for the flight crew before the Ground Test Vehicle is available. Engineering mockups and developmental hardware will be used for this purpose.

A high-level program schedule, based on the schedule analyses referenced above, is shown in Figure 11. This high-level schedule includes the Phase B study activity and presumes a new start in FY85.

SOC-1046



NOTE: RESUPPLY LAUNCHES ON 3 – MONTH CENTERS AFTER IOC

Figure 11 SOC Reference Program Summary Schedule

7.0 REFERENCE SOC BUILDUP OPTIONS AND FUNDING PROFILES

Funding profiles were investigatd for three program options. These were (1) direct buildup to the operational SOC configuration; (2) buildup to the initial SOC configuration with a two-year gap before resuming buildup to the operational SOC; (3) direct buildup to the operational SOC core with deferral of mission equipment such as the mobile crane and OTV hangars.

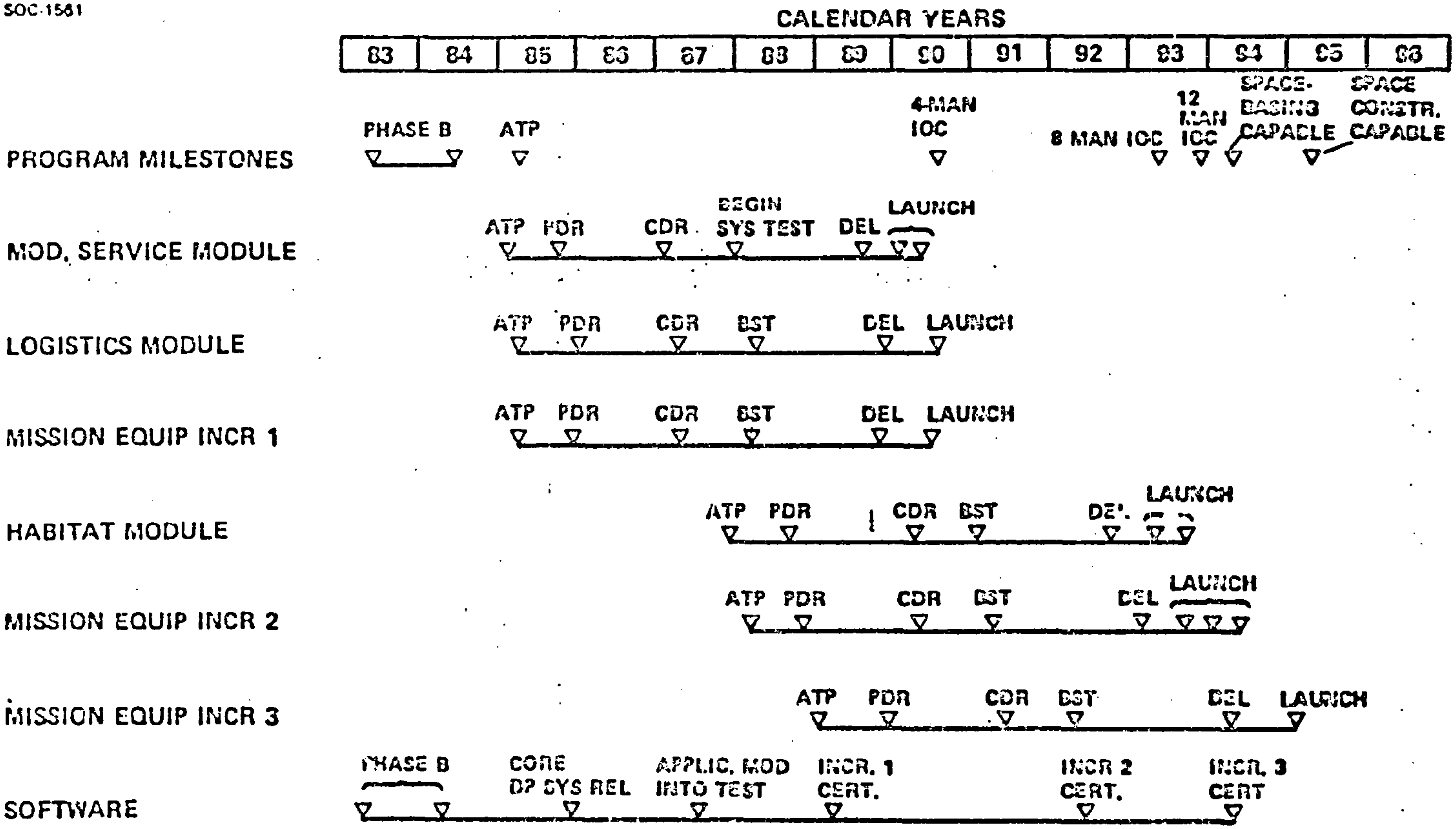
The principal finding from the buildup options analysis for the reference SOC was that stretching out the program was not an effective way of reducing peak developmental funding. Higher costs of engineering and manufacturing activities, caused by program discontinuities, largely offset peak funding reductions realized by the slower schedule. Deferring some of the mission equipment (cherrypicker, OTV hangar, etc.) is a more effective means of reducing peak funding.

8.0 FUNDING SPREAD ESTIMATES FOR ALTERNATIVE PROGRAM BUILD-UP SEQUENCES

A build-up sequence for the alternative SOC design was analyzed to determine its funding requirements. It is tailored to the mission needs ascertained by the median traffic model analysis. The build-up schedule is shown in Figure 12. This build-up schedule uses the habitable service module design concept to permit initial operations with only two service modules and a logistics module placed in orbit. The development of the habitat module is deferred so that it becomes available in the fourth year of the flight operations program. In this alternative, space-basing of OTV operations begins in the same year so that as the SOC is built-up to reference capability the equipment and facilities for OTV space-basing are added.

In 1995, additional construction equipment is added for assembly and test of large platform spacecraft. Funding requirements are shown in Figure 13 and Tables 4 and 5. The peak funding is reduced by about 25% as compared to the reference program, and the peak occurs four years after program start rather than three years. The funding peak could be further reduced by an additional year's deferral of the habitat module. The additional deferral, however, would delay certain mission capabilities enough to impact accomplishment of the mission model. Actual timing of the startup of the habitat module can, of course, be adjusted to meet mission needs as they actually develop.

SOC-1561



MISSION EQUIPMENT

INCR. 1: HANGARS, AIRLOCKS, AND RMS-TYPE ARM WITH EVA WORK STATION
INCR. 2: MOBILE CHERRYPICKER & TRACKS, SPACE-BASING EQUIPMENT; DOCKING TUNNEL
INCR. 3: CONSTRUCTION EQUIPMENT

Figure 12. SOC Evolutionary Development Schedule

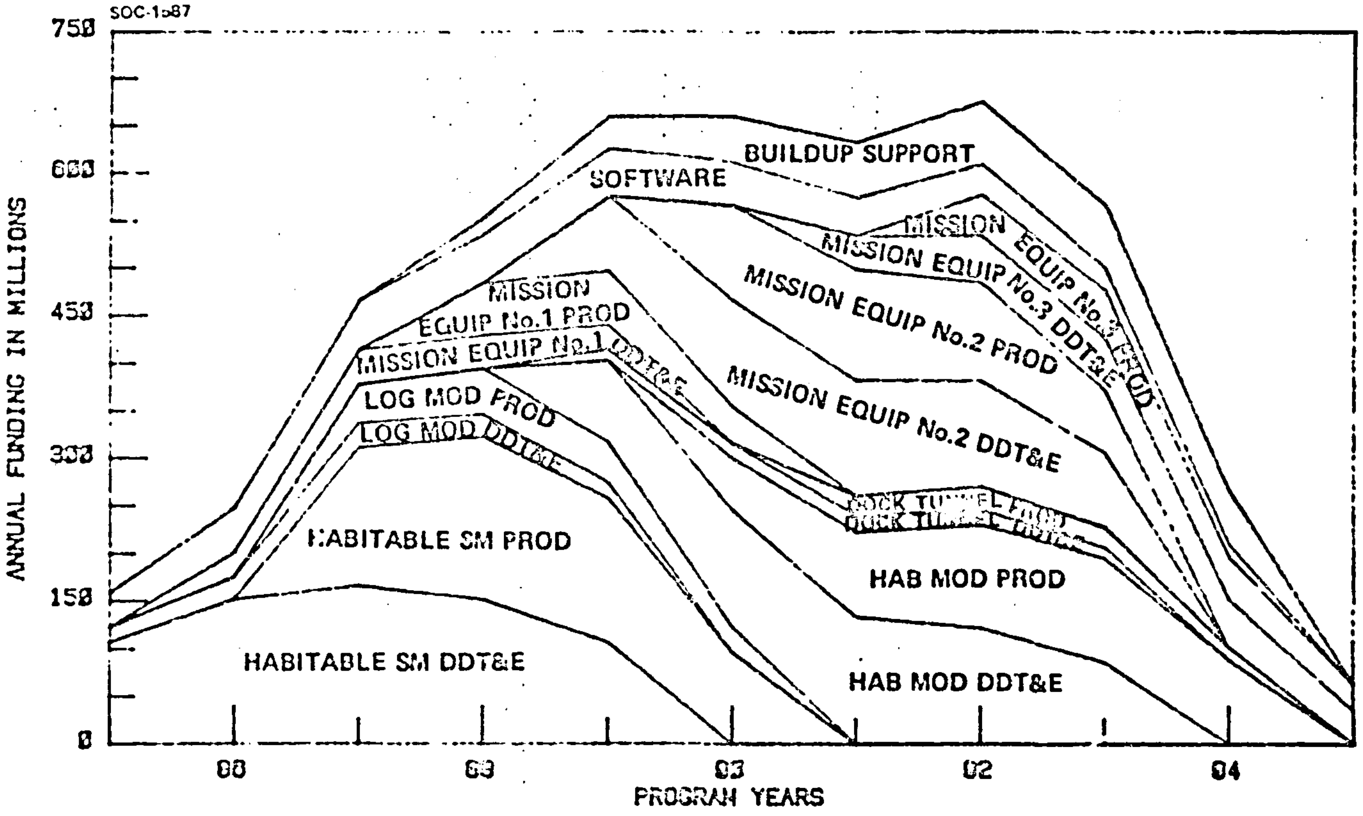


Figure 13. SOC Evolutionary Program- Development Funding Keyed to Mission Needs

SPACE OPERATIONS CENTER

NASA

SOC-1573

Table 4.

Elements of Cost - Modular Evolutionary Program

	INITIAL (4 CREW)		OPERATIONAL (12 CREW)		GROWTH (CONSTR. EQUIP. ADDED)	
	DDT&E	PRODUCTION	DDT&E	PRODUCTION	DDT&E	PRODUCTION
MODIFIED SERVICE MODULES	684	564				
LOGISTICS MODULES	108	158				
HABITAT MODULES			550	450		
DOCKING TUNNEL			70	80		
AIRLOCKS	30	50				
HANGARS	70	25		25		
SUPPORT EQUIPMENT	22	76	275	195	25	15
OTV SPACE-BASING EQUIP			200	150		
CONSTRUCTION EQUIP			25	15	250	150
SOFTWARE	150		150		90	
BUILDUP SUPPORT	50	75	100	120		
NO. OF SHUTTLE FLIGHTS		(3)		(6)		(2)
SUBTOTALS	1112	943	1370	1035	365	165
TOTALS	2060		2405 ADDED; TOTAL $$ 4465		530 ADDED; TOTAL 4995	

NOTES:
1) COSTS ARE 1980 DOLLARS IN MILLIONS
2) SHUTTLE LAUNCH COSTS NOT INCLUDED
3) LEVEL I PROGRAM INTEGRATION COSTS NOT INCLUDED

TABLE 5
YEAR-BY-YEAR FUNDING FOR SOC EVOLUTIONARY PROGRAM

	Program Year										
Program Elements	1	2	3	4	5	6	7	8	9	10	11
Habitable SM DDT&E	107	152	166	152	107	0	0	0	0	0	0
Habitable SM Prod	0	0	146	171	151	96	0	0	0	0	0
Logistics MOD DDT&E	17	24	26	24	17	0	0	0	0	0	0
Logistics MOD Prod	0	0	41	48	42	27	0	0	0	0	0
Habitat MOD DDT&E	0	0	0	0	86	122	134	122	86	0	0
Habitat MOD Production	0	0	0	0	0	55	89	108	110	88	0
Docking Tunnel DDT&E	0	0	0	0	11	16	17	16	11	0	0
Docking Tunnel Prod	0	0	0	0	0	0	21	24	21	14	0
Mission Equip #1 DDT&E	0	26	35	35	26	0	0	0	0	0	0
Mission Equip #1 Prod	0	0	0	54	57	39	0	0	0	0	0
Mission Equip #2 DDT&E	0	0	0	0	78	111	121	111	78	0	0
Mission Equip #2 Prod	0	0	0	0	0	100	117	103	66	0	0
Mission Equip #3 DDT&E	0	0	0	0	0	0	35	50	55	50	35
Mission Equip #3 Prod	0	0	0	0	0	0	0	43	50	44	28
Software	36	46	51	52	50	46	40	33	23	13	0
Build-up Support	0	0	0	18	34	48	59	65	66	56	0
Total	160	248	465	554	659	660	633	675	566	265	63

D180-26785-2

9.0 SOC COST/BENEFIT ANALYSES

In order to develop a preliminary comparison of potential SOC benefits to estimated SOC costs, the costs were allocated to categories of research and development, investment, and operations. These were then contrasted with potential benefits, including increased business and economic growth, cost savings for conducting space research needing crew involvement, and cost savings for space operations.

The research and development costs for the Space Operations Center, including all modules, but excluding production and production-related costs, were estimated to be approximately $4 billion in 1982 dollars. A potential benefit accruing from this development is improved marketability of U.S. space systems and space operations to support worldwide commercial uses of space. This improvement would stem from lower cost of operations and ability to provide types of service not elsewhere available.

A representative all-up shuttle flight, using an advanced-technology upper stage, will be valued at about $200 million. This figure includes the shuttle and upper stage costs as well as the cost of the spacecraft being launched. It is representative of a platform-class communications satellite of the type forecast for use in the 1990s.

There are several ways of evaluating the economic benefit derived from this representative flight. The most favorable is a holistic view, predicting that the competitive advantage deriving from superior space operations capabilities would attract not only additional launch services business, but also additional spacecraft development and production business. In this view, the entire value of the launch is an economic benefit to the U.S.

A less favorable view is one in which only the launch service business is a net inflow to the U.S. In this instance, the economic benefit will be more like $60 million.

If added spacecraft and launch services business is attracted from foreign competition, then an indirect multiplier should be included in the calculation.

Indirect multipliers have been variously estimated from two to seven. (Indirect multipliers do not apply in the same way to economic activity transferred from one economic sector to another within the U.S. Most sectors have similar multipliers, and the losing sector loses its multiplier effect as well. Further, an economist might argue that imports must be balanced by exports, but this seems to be more true in economic theory than it is in actual practice.)

If the research and development investment in the Space Operations Center is retired over a 15-year period at a 10% discount, the annual cost of retirement of this investment is approximately $525 million. Thus, to break even, the availability of the SOC for transportation and satellite servicing operations needs to attract roughly two-and-one-half Shuttle flights per year to the United States from foreign suppliers of such service. This assumes that the entire value of the flight is a benefit, but that there is no indirect multiplier. With the indirect multiplier, even the attracting of only one equivalent Shuttle flight per year to the U.S. system might well amortize the R&D investment in the Space Operations Center. If only the launch services business is a net benefit, several flights of added business would be needed to break even. Table 6 summarizes sample calculations.

In order to compare investment and operations costs with the benefits of the new capabilities and cost savings, the investment and operations costs were lumped together in order to determine an equivalent cost per man-day for SOC operations. Table 7 presents a summary of this calculation for the 12-man SOC configuration indicated as desirable by the median traffic model mission needs analysis.

One of the benefits accrued by availability of the Space Operation Center is the ability to conduct research and applications missions at less cost than would be the case without the Space Operations Center available. Table 8 compares the cost per man-day for research and applications missions with Shuttle and Spacelab. Also included in the Table is an estimate of the relevant Shuttle and Spacelab costs. Since U.S. space transportation pricing policy will be to make the pricing for space transportation operations commensurate with actual costs after 1983, the costs used here, although derived from the STS reimbursement guide, have been adjusted for estimated actual costs.

Table 6. Research and Development Amortization

SOC-1552

R&D COST ESTIMATE (1982$)

INITIAL	2273M
INCREMENT FOR OPERATIONAL EQUIPMENT	908M
INCREMENT FOR SPACE-BASING AND CONSTRUCTION EQUIP.	853M
TOTAL	4034

ANNUAL COST FACTOR

10% DISCOUNT & 15-YR WRITEOFF:

$$F = \frac{0.10}{1 - \frac{1}{1.1^{15}}} = 0.131$$

ANNUAL COST = 0.131 X 4034M

= $530M

VALUE OF A SHUTTLE FLIGHT

SHUTTLE FLIGHT	50M
UPPER STAGE USE CHARGE	10M
SPACECRAFT	150M
ROUGHLY	200M

INDIRECT MULTIPLIER—
VARIOUSLY ESTIMATED AS 2 TO 7.

SOC OPERATIONAL BENEFITS NEED TO ATTRACT 0.4 TO 1.3 EQUIVALENT SHUTTLE FLIGHTS IN BUSSINESS EACH YEAR

DIRECTLY ATTRIBUTABLE JOBS: 5000 TO 10,000 PER FLIGHT PER YEAR.

Table 7. SOC Investment and Operations Amortization

SOC-1553

STRAIGHT-LINE AMORTIZATION		CREW SIZE (MAX) 12
15 YEARS	$250M	WORK DAYS/YR 313
RESUPPLY PER YEAR	$200M	3756 MAN DAYS/YEAR
FLIGHT CREWS - 3 X 12 @ $1M/YR	$ 36M	OR
OPERATIONS SUPPORT 500 PEOPLE @ $40K	$ 20M	$42M FOR A RESEARCH PROJECT AVERAGING ONE FULL-TIME CREW MEMBER FOR A YEAR.
TOTAL –	$506M/YR	

* 17-TONNE PAYLOAD YIELDS USE CHARGE FACTOR OF 0.768

SHUTTLE CHARGE = 0.768 X 50M =	$38.4M
EXTRA DAY	$ 1 M
LOGISTICS MODULE OPERATIONS	$10 M (GUESS)
	$49.4M, FOUR TIMES PER YEAR

Table 8. Shuttle-Spacelab Comparison

SOC-1554

	REIMBURSEMENT GUIDE		ESTIMATED ACTUAL		SOC RESUPPLY
	1975$	1982$	1982$		1982$
SHUTTLE	18	28	50	(X.768)	38.4
ELEC. PWR CRYO KIT	0.3	0.5	1		–
EXTRA DAYS (9)	2.7	4	9	(1)	1
P/L SPECIALISTS (4)	1.2	1.85	2		–
SPACE LAB	5.4	8.3	20	LM OPS	10
			82		49.4

TAKING CREDIT FOR ONE FLIGHT CREW MEMBER, SHUTTLE/SPACELAB MANDAY COST IS

$$\frac{\$82M}{5 \times 10} = \$1.64M$$

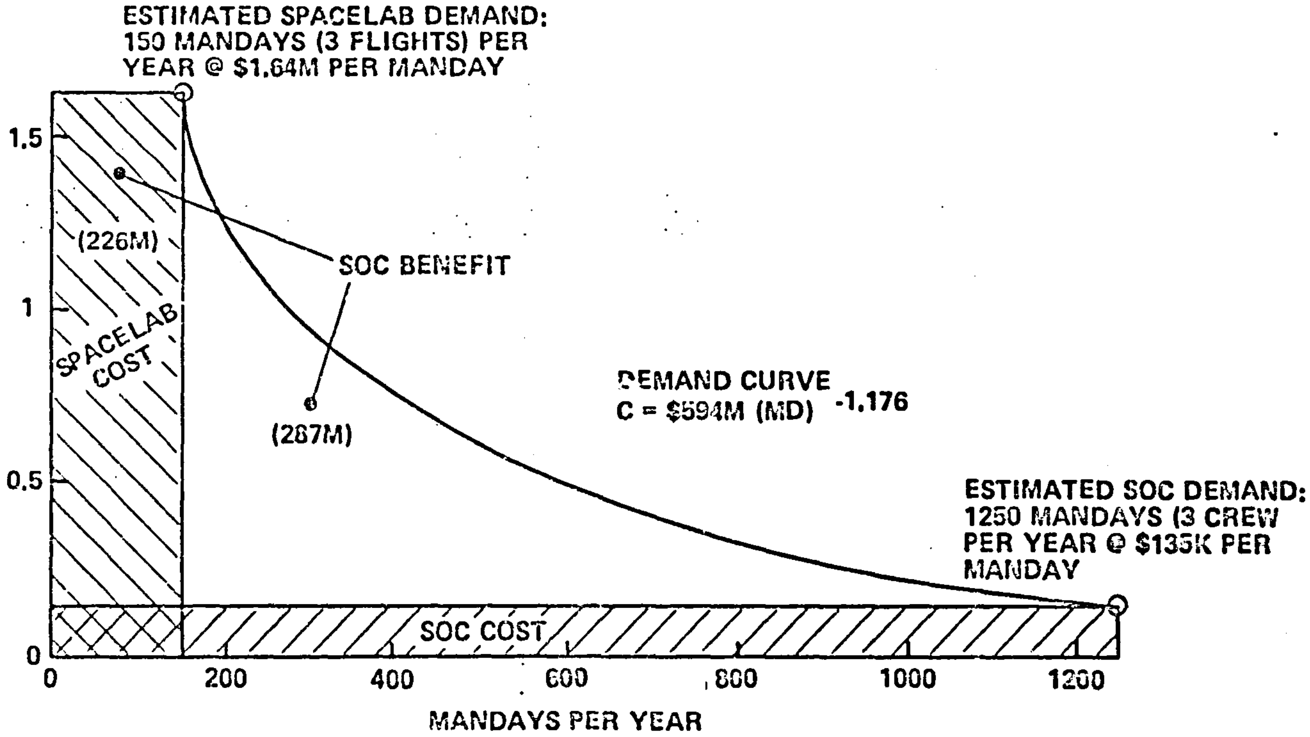
To estimate the benefit from the reduced costs for SOC operations, we used an elastic demand model. This concept and the benefit calculations are summarized in Figure 14. It is estimated that the demand for research and applications missions at Spacelab costs and the timeframe of interest would be met by approximately three 10-day Spacelab missions per year. The estimated research activity level for materials processing used in this example for the Space Operations Center median traffic model is approximately 900 man-days per year, or six times that which would be conducted with the Shuttle and Spacelab. However, were costs to remain at the Shuttle Spacelab level, this additional research would not be conducted because it is too expensive. The elastic demand model says that as costs are reduced additional demand will come forth.

The benefit derived from the reduced cost of SOC thus is far less than one would determine from assuming that all of the additional research and applications capability of SOC would be accomplished at a value equal to that for operating Shuttle and Spacelab.

The demand for SOC research applications was estimated for the three mission models. The differences in demand for the three models was not attributed to differences in cost, but rather reflect an uncertainty in the actual level of demand. This could be regarded as an uncertainty in the elasticity of demand.

The elasticity of demand was modeled by applying an exponent to the cost, in the form illustrated in Figure 14. As the predicted demand is varied, so are the parameters in the equation. A summary of results for the three traffic models is as follows:

Model	Average Research Crew Size	Exponent	Multiplier	Variable Benefit	Total Annual Benefit Including Fixed Value of $226 M
Low	2.93	-1.38	1.66×10^9	$218 M	$444 M
Median	5.12	-1.056	0.325×10^9	$350 M	$576 M
High	9.46	-0.838	0.109×10^9	$564 M	$790 M



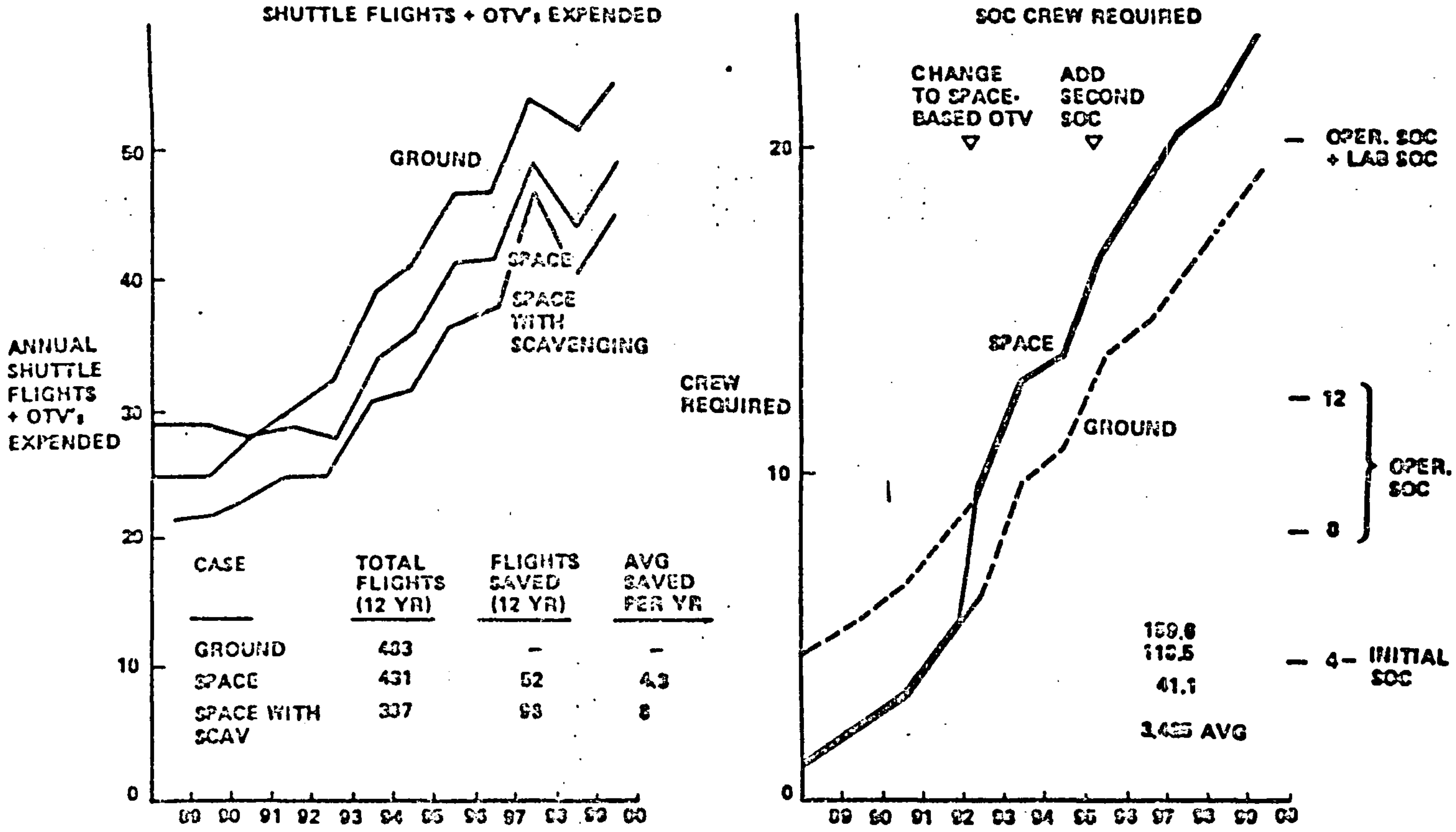
TOTAL BENEFIT: $513M PER YEAR

Figure 14. Research and Applications Benefits Estimate Elastic Demand Model

A third category of benefits arises from the reduced number of space transportation flights required to service the traffic model with the availability of the Space Operations Center. This calculation is presented in Figure 15. The benefit of reduced numbers of Shuttle flights exceeds the cost of the additional SOC crew required to service these flights for the space-based OTV possible only with a Space Operations Center. The further added benefit of the use of external tank scavenging is comparable to that for space-basing of the OTV. This benefit has a net present value at the time of development of the scavenging capability of approximately a billion dollars for the median traffic model.

The calculations presented did not take credit for reduced time on orbit for the Space Shuttle Orbiters for the presence of SOC. Earlier estimates have indicated that the reduced on-orbit time will reduce the required fleet size by roughly one Orbiter. This reduction in fleet size represents an additional billion dollars in benefit for the Space Operations Center.

SOC 1581



CASE	TOTAL FLIGHTS (12 YR)	FLIGHTS SAVED (12 YR)	AVG SAVED PER YR
GROUND	483	–	–
SPACE	431	52	4.3
SPACE WITH SCAV	387	93	8

SPACE-BASING SAVES 52 @ $40M = $2.031B

SPACE-BASING COSTS:
3.425 AVG EXTRA CREW X 12 YR X 312 WORK-DAYS/YR X $130K/MANDAY = $1.67B

Figure 15. OTV Basing: Space vs Ground (Median Traffic Model)

10.0 RECOMMENDED TECHNOLOGY

A key part of programmatic considerations is the selection of technology levels for implementation. This represents a tradeoff among cost, risk, schedule, and the desire to apply enough technology advancement that the planned system will not be obsolete when operational. Conscious technology selections were made for all of the SOC subsystems. The SOC Technology Identification Support Study Final Report (Boeing-23) contains the results of the technology identification analyses. Table 9 summarizes the technology recommendations developed in this study. These recommendations were also used as a basis for technology advancement recommendations.

Certain technology advancement needs carry with them significant schedule implications. Most important are the areas for which life testing of flight prototype hardware may be needed as a part of the development program. Two such areas for SOC are the EC/LS systems and the electrical power system. In both areas, technology advancements are proposed, the proper operation of the hardware is critical to crew safety, and the required hardware life is challenging. These areas merit special consideration in developing plans to proceed with technology advancement so as to accomplish the life tests in a timely manner.

Another area needing special attention is software. Our estimates of the desired schedule for SOC software development showed that it will require longer than the hardware. The software schedule can be accelerated, but only at higher cost and greater risk. The problem can be alleviated by carrying out a data management architecture technology program and by initiating software design and development as a part of the SOC Phase B studies.

Table 9. Recommended Technology Levels

SOC-1057

SYSTEM OR SUBSYSTEM	RECOMMENDED LEVEL	STATUS	RATIONALE FOR SELECTION
PRIMARY STRUCTURE	WELDED* ALUMINUM (NEW DESIGN)	DEVELOPED	• BECAUSE OF COLLISIONS & FIRE CRITERIA, NO SIGNIFICANT BENEFIT FROM ALTERNATIVES
BOOM & TRACK STRUCTURES	GR-EP	DEVELOPED; SOME CONCERN ABOUT LIFE IN SPACE	• NO SUITABLE EXISTING DESIGN STIFFNESS & MASS ADVANTAGES
SECONDARY STRUCTURES	ALUMINUM OR GR-AL	GR-AL IS IN DEVELOPMENT. NOT MUCH PROPERTIES DATA	• GR-AL OFFERS WEIGHT & STIFFNESS ADVANTAGES • FIRE CRITERIA PRECLUDE GR-EP • ALUMINUM IS ADEQUATE
THERMAL CONTROL • HAB MODULE COATING	REFRESHABLE SELECTIVE COATING	RESEARCH	• SELECTIVE COATINGS ESSENTIAL DUE TO SUN ANGLES • DEGRADATION IS A PROBLEM FOR 10-YEAR LIFE • ALTERNATIVE IS LONG-LIFE COATING

Table 9. (Cont'd)

SYSTEM OR SUBSYSTEM	RECOMMENDED LEVEL	STATUS	RATIONALE FOR SELECTION
SERVICE MODULE RADIATORS	CONSTRUCTABLE HEATPIPE	IN TECHNOLOGY DEVELOPMENT	• NOT ENOUGH AREA ON SM EXTERIOR • PACKAGING ADVANTAGES • READILY REPAIRABLE
FLUID LOOPS	SHUTTLE	DEVELOPED; UPGRADE DESIGN TO ENHANCE LIFE & PROVIDE FOR ONBOARD MAINTEN-ANCE	• SHUTTLE TECHNOLOGY IS ADEQUATE
PROPULSION	HYDRAZINE MONO-PROPELLANT EVALUATE ELECTRICAL HEAT AUGMENTATION (RAISE ISP TO 300) O_2-H_2 GAS WITH REGENERATIVE FUEL CELL ENERGY STORAGE	DEVELOPED; SMALL HEAT-AUGMENTED THRUSTERS IN DEVELOPMENT	• LOW CONTAMINATION; SIMPLE; RELIABLE • HEATED THRUSTERS APPROACH BI-PROP ISP • O_2-H_2 GAS PROVIDES 375 Isp & ELIMIMATES HYDRAZINE
SOLAR ARRAY	PEP-TYPE WITH LARGE AREA CELLS	IN TECHNOLOGY DEVELOPMENT	• PACKAGING ADVANTAGES • LOW WEIGHT • LARGE AREA CELLS OFFER COST ADVANTAGES

Table 9. (Cont'd)

SYSTEM OR SUBSYSTEM	RECOMMENDED LEVEL	STATUS	RATIONALE FOR SELECTION
ENERGY STORAGE	NICKEL-HYDROGEN OR REGENERATIVE FUEL CELLS	IN TECHNOLOGY DEVELOPMENT; SMALL NiH2 BATTERIES FOR FOR GEO SATELLITES	NiH2 ABOUT HALF THE WEIGHT OF NICKEL-CADIUM IN THIS APPLICATION REGENERATIVE FUEL CELLS LIGHTER THAN NiH2
ENVIRONMENTAL CONTROL & LIFE SUPPORT	RECYCLED WATER AND OXYGEN	IN TECHNOLOGY DEVELOPMENT; INTEG-RATED TESTING OF EXPERIMENTAL HARDWARE	GREAT SAVINGS IN RESUPPLY COST
CREW SYSTEMS (FOOD, WASTE, HYGIENE)	NEW DESIGN EXCEPT FOR SHUTTLE TOILET	SHUTTLE TOILET DEVELOPED OTHER ITEMS CONCEPTED	NO SUITABLE AVAILABLE EQUIPEMENT EXCEPT SHUTTLE TOILET
EVA EQUIPMENT	SHUTTLE WITH SLIGHTLY HIGHER PRESSURE SUIT AND ICE PACK THERMAL CONTROL	SHUTTLE EQUIPMENT DEVELOPED MODIFICATIONS CONCEPTUALLY DESIGNED	ELIMINATE EVA PREBREATHE MINIMIZE WATER RESUPPLY SHUTTLE TECHNOLOGY IS ADEQUATE WITH THESE IMPROVEMENTS

Table 9. (Cont'd)

SOC-1052

SYSTEM OR SUBSYSTEM	RECOMMENDED LEVEL	STATUS	RATIONALE FOR SELECTION
FLIGHT CONTROL SENSORS & ACTUATION	CURRENT TECHNOLOGY WITH DESIGN MODS FOR IN-SPACE MAINTENANCE	TECHNOLOGY IS DEVELOPED	- CURRENT TECHNOLOGY IS ADEQUATE - IN-SPACE MAINTENANCE REQUIRED FOR 10-YEAR LIFE
FLIGHT CONTROL COMPUTATION	32-BIT MICROPROCESSORS AND ADAPTIVE CONTROL ALGORITHMS	- MICROS IN TECHNOLOGY DEVELOPMENT FOR COMMERCIAL & MILITARY APPLICATIONS - ALGORITHMS IN RESEARCH STAGE	- PROCESSING POWER NEEDED - SOFTWARE COST SAVINGS - ADAPTIVE CONTROL ESSENTIAL FOR VARIABLE CONFIGURATION
COMMUNICATIONS	- CONVENTIONAL S-BAND, K-BAND & UHF, PLUS	- DEVELOPED	- NECESSARY TO TALK TO EXISTING VEHICLES
	- MM-WAVE FOR RELAY & RADAR	- IN TECHNOLOGY DEVELOPMENT	- REDUCED RFI
	- POTENTIAL USE OF LF FOR EVA	- DEVELOPED	- ENHANCED COVERAGE

Table 9. (Cont'd)

SOC-1053

SYSTEM OR SUBSYSTEM	RECOMMENDED LEVEL	STATUS	RATIONALE FOR SELECTION
DATA MANAGEMENT			
- PROCESSORS	32-BIT MICROPROCESSORS	IN DEVELOPMENT FOR COMMERCIAL & MILITARY APPLICATIONS	• PROCESSING POWER • SOFTWARE COST SAVINGS
- SOFTWARE	ADA (NEW HIGH-ORDER LANGUAGE)	COMPILERS UNDER DEVELOPMENT BY DOD	• WILL BECOME A STANDARD • RICH & POWERFUL LANGUAGE
- ARCHITECTURE	DISTRIBUTED, HIERARCHICAL	- MANY DISTRIBUTED SYSTEMS EXIST - PROBABLY NEED NEW BUS PROTOCOL	• NECESSARY BECAUSE OF SOC MODULARITY • COST SAVINGS IN SOFTWARE AND SYSTEM INTEGRATION
- DATA BUS	FIBER OPTICS	PARTIALLY DEVELOPED	• HIGH SPEED • EMI IMMUNITY

11.0 PROGRAM RECOMMENDATIONS

Pre-Phase B

There is a near-term need for additional analysis and definition of key SOC subsystems. This can be done with confidence that the results will be applicable to the system design that is developed by the Phase B preliminary design; the technical definitions of these subsystems are nearly independent of specific mission applications and are relatively independent of configuration. These studies could provide valuable technical inputs to Phase B and probably shorten the time needed to conduct a Phase B preliminary design. Specific recommended studies are as follows:

Comparative design definition of battery and regenerative fuel cell electric power systems. Preliminary studies, summarized in the following section of this report, indicate significant advantages for the regenerative concept, in which high-pressure electrolysis units are used to regenerate reactants from water. A comparative design study in greater depth is needed to make a final selection. This study should also investigate design integration of the solar array masts. These masts will be quite complete, carrying electric power, data, thermal control, propulsion, and communications services. They must be deployed when the electric power section or service module for the SOC is launched.

Data management and software systems analysis. Studies to date have indicated a strong preference for advanced technology microprocessors, and a federated processing system architecture. The new standard DoD high-level language, ADA, offers great promise for reducing software costs. A systems analysis and design study should be carried out, including high-level preliminary design of software elements needed early in the program, integration of displays and controls considerations, and selection of a specific architecture and communications protocol. Even though the architecture might be changed later in Phase B, the results of the pre-Phase B study would be invaluable as an input, allowing the Phase B study to immediately get the design specifics.

Flight control and dynamics analysis. This study would have to use representative configurations, but the results would be generally applicable to other configurations in the SOC class. Dynamics modeling is needed to develop the requirements for technology advancements in adaptive control and flight control systems. The dynamics modeling should include analysis of zero-g slosh dynamics with cryogenic propellant storage for orbit transfer vehicles.

Communications system analysis. An analysis, conceptual design, and technology assessment should be made for millimeter-wave communications systems and traffic control radar. Needs for high data rates and immunity from RFI can best be met by millimeter-wave systems.

Phase B

Phase B studies should be vertically-integrated, even though later procurements may be implemented as separate contracts for each SOC module. The vertical integration, i.e., preliminary design of the entire system, is necessary to obtain the proper understanding of system, subsystem, and operational interrelationships. Phase B should concentrate on the modules to be developed first, but should render sufficient design detail on later modules that all interfaces are thoroughly understood, and so that specifications can be written for the later modules without resort to further Phase B study.

Development

The alternate system option is recommended for development, rather than the reference design. The alternate system better meets presently-identified mission needs and is more compatible with expected funding capabilities.

Development of the SOC and of an advanced-technology orbit transfer vehicle should be coordinated. Both are needed to satisfy forecast mission needs. Transition to space-based operation of the orbit transfer vehicle should occur as soon as practical, but initial operation should be ground-based to (1) develop operational experience with the vehicle, and (2) allow time for development of efficient zero-g propellant transfer and management systems.

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